Overview of Systems Engineering Research at Georgia Tech

Russell Peak and Doug Bodner  
(presenters)  
Carlee Bishop, Tommer Ender, Tom McDermott  
Leon McGinnis, Chris Paredis, Bill Rouse  
(other main contributors)
• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)  
    Bishop, et al.
  – Tennenbaum Institute (TI)  
    Bodner, Rouse, et al.
  – GTRI SE Initiative  
    Ender, et al.
  – Aerospace Systems Design Lab (ASDL)  
    Mavris, et al.
  – Model-Based SE Center (MBSEC)  
    McGinnis, Paredis, Peak, et al.

• Summary
# Georgia Tech Fun Facts

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1885</td>
<td>Founded</td>
<td>in Atlanta</td>
</tr>
<tr>
<td>1903</td>
<td>First full-time football coach</td>
<td>John Heisman</td>
</tr>
<tr>
<td>1948</td>
<td>Renamed</td>
<td>Georgia Institute of Technology</td>
</tr>
<tr>
<td>1996</td>
<td>Served as Olympic Village for</td>
<td>10,000+ athletes/staff</td>
</tr>
</tbody>
</table>

**Faculty**
- 5 Professors
- 5 Shop Supervisors

**Students**
- 129 undergrads in Mechanical Engineering

**Mascots**
- [Image of mascot]
Georgia Tech Statistics

Students
- undergrad: ~12,000
- grad: ~8,000
- total: ~20,000

engineering: ~11,000

Contents

• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)
    Bishop, et al.
  – Tennenbaum Institute (TI)
    Bodner, Rouse, et al.
  – GTRI SE Initiative
    Ender, et al.
  – Aerospace Systems Design Lab (ASDL)
    Mavris, et al.
  – Model-Based SE Center (MBSEC)
    McGinnis, Paredis, Peak, et al.

• Summary
Professional Masters in Applied Systems Engineering
www.pmase.gatech.edu

The degree program:

• Targeted to working professionals (5+ years experience)
• Convenient format combining distance learning and onsite interactions
• An applied degree taught from an enterprise view
• Relevant tools for solving real world problems
The PMASE Curriculum

Core Curriculum
- ASE 6001: Fund in Modern SE
- ASE 6002: Sys Design & Analysis
- ASE 6003: M&S for SE
- ASE 6004: Leading SE Teams
- ASE 60X5: Advanced Topics in SE
  - SysML
  - HSI
- ASE 6006: SE Lab

Complex Systems Curriculum
- ASE 61X1: Domain Elective in Synthesis & Analysis
  - Vehicles
  - Sensors
  - Info Systems
  - HSI
- ASE 6102: SOS & Architectures
- ASE 6103: Lifecycle & Integration
- ASE 6104: Complex Systems Capstone

Most material is also available in short course format in the SE certificate program (www.pe.gatech.edu)
• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)  
    Bishop, et al.
  – Tennenbaum Institute (TI)  
    Bodner, Rouse, et al.
  – GTRI SE Initiative  
    Ender, et al.
  – Aerospace Systems Design Lab (ASDL)  
    Mavris, et al.
  – Model-Based SE Center (MBSEC)  
    McGinnis, Paredis, Peak, et al.

• Summary
Knowledge and Skills for Enterprise Transformation.

- Interdisciplinary research
- Understand and enable fundamental change of private and public sector enterprises
- Defense acquisition
- Services
- Energy
- Enterprise integration
- Global manufacturing
- Health care
Defense Acquisition

Weapons systems progress through the acquisition lifecycle, including sustainment. The impacts on cost, schedule performance and risk are compiled.

- Goal – investigate relationships between evolutionary acquisition, system modularity and production level
- Findings
  - Evolutionary acquisition tends to reduce program costs but increase enterprise costs
  - Modularity tends to increase development cost and decrease sustainment cost
  - High modularity tends to lower overall acquisition cost and mitigates the overall cost associated with high production
- Sponsor – Navy/NPS
Defense Acquisition and Organizational Simulation

- Goal – represent organizational phenomena in simulation models (agent-based, discrete-event, system dynamics)
- Incorporate interactive computing concepts (character programming and drama management)
- Application to Predator acquisition:
  - Multi-actor decisions
  - Lead service selection
  - Military utility determination
- Sponsor – Air Force
Defense Acquisition and Systems Engineering (RT-16)

- Personality Background Characteristics Model
- SE Competency Taxonomy
- Learning Moments

User Profile

- Presentation Engine
  - User decisions
  - Results (schedule/budget)

- Simulation Engine
  - Program results (user decisions & randomness)
  - NPC Engine
  - Colleague interactions

Learning/Reflection

Framework exercise

Experience Database

Sponsor – SERC/DAU
Partners – GT, Purdue, Stevens, USC

Knowledge and Skills for Enterprise Transformation.
Services

Requirements and designs are represented as information artifacts that evolve and change as they traverse processes.

- Services constitute a majority of GDP
- Engineering design as a service – computer servers
- Time to market is key
- GT modeled and simulated computer server design processes
- Organizational designs and skill level mixes have a major impact on service effectiveness
- Sponsor – IBM
Energy

- Wind energy systems integrators face major cost issues in transport of components
- Multiples of $100M annually
- GT developed an optimization tool for sourcing and transport of components
- Spreadsheet-based with trade-offs between usability and speed
- 10-15% cost reduction on sample runs vs. manual approach
- Sponsor – GE Energy
Knowledge and Skills for Enterprise Transformation.

Enterprise IT Integration (RT-25)

- Enterprises face new challenges, requiring new capabilities
- This involves integration of new capabilities
- How are these translated in a disciplined manner to IT requirements
- This occurs in an evolutionary environment
- Need for tools
  - Represent capabilities and requirements
  - Facilitate experimentation and what-if analysis
- Sponsor – SERC
- Partners – GT and USC
Contents

• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)
    *Bishop, et al.*
  – Tennenbaum Institute (TI)
    *Bodner, Rouse, et al.*
  – GTRI SE Initiative
    *Ender, et al.*
  – Aerospace Systems Design Lab (ASDL)
    *Mavris, et al.*
  – Model-Based SE Center (MBSEC)
    *McGinnis, Paredis, Peak, et al.*

• Summary
Collaborative Decision Making

Decision-makers afforded novel real-time, panoramic view of trade-offs and parametric sensitivities via advanced visualization features.

Research conducted on capability-focused and inverse design to identify solutions that meet dynamic requirements.

Real-time collaboration and decision making in a secure environment to solve real-world problems.
Marine Personnel Carrier (MPC)

2000 — 2050

AAV
MRAP

Marine Corps future for tactical mobility

Performance
Payload
Protection

Mobility
C-17 Transportable
Swim/Fording

IED Protection
Direct Fire Protection
Scalable Armor

Payload
Combat Loaded Marines
Days of Supplies

Performance, payload, protection

Optimization of the balance of performance, payload, and protection for the complete system

Goal is to create achievable and affordable requirements in the aggregate before Tech Development (TD) phase
Requirements Definition
Current toolset used to analyze selected mobility requirements and associated costs

Source Selection
Current toolset may be used to assist source selection planning

Outcomes
- Better defined requirements with enabling performance
- Getting proposals that are closer to our goals, reducing risk to cost and schedule
- Guidance towards source selection
The suite of tools are used together to allow the government to generate optimized performance targets.

Output: Recommendations for a balanced, achievable requirements document for MPC
**Navigate through the possible combinations through:**

- A series of technology compatibilities (i.e. some technologies options for one subsystem may not be compatible with technologies in another subsystem)
- Technology filters (i.e. all must be at least a TRL = 8)
- Technologies that will benefit important requirements

---

**MPC Interactive Reconfigurable Matrix of Alternatives (IRMA)**

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Technology</th>
<th>Technology</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swim Cap</td>
<td>Integral Swim</td>
<td>Jet Pump - Clutch Drives</td>
<td>Live Axle (front)</td>
</tr>
<tr>
<td>Swim Cap</td>
<td>Swim Propulsion</td>
<td>Live Axle</td>
<td>Leaf</td>
</tr>
<tr>
<td>Front Suspension Architecture</td>
<td>SLA (front)</td>
<td>2-stage switchable</td>
<td>L &amp; R</td>
</tr>
<tr>
<td>Rear Suspension Architecture</td>
<td>SLA</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Suspension Actuation - Spring</td>
<td>Coil Springs</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Suspension Actuation - Damper</td>
<td>Passive</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Steering</td>
<td>Power Assisted</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Chassis Systems - Brakes</td>
<td>Hydraulic Brakes</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Chassis - Run Flat</td>
<td>Hatchback</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Chassis - Tires</td>
<td>Michelin XM</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain - Main Powerplant</td>
<td>CI-solex</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Electrical Power Generation</td>
<td>Alternator</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Electrical Storage Architecture</td>
<td>Lead Acid</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain Cooling - Radiator</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain Cooling - Charged Air Cooler</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain Cooling - Oil Cooler</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain Cooling - Fuel Cooler</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain Cooling - Condenser</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Powertrain Cooling - Engine Cooling Fan</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Thermal Systems - Climate Control</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Thermal Systems - Waste Heat Recovery</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Driveline - Transmission</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Driveline - Transfer Case</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Driveline - Differentials</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Driveline - Hubs</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>Driveline - Shafts</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
<tr>
<td>TRL</td>
<td>Rigid Aluminum Tube</td>
<td>Continuously Adjustable</td>
<td>L, 2, 3, 4</td>
</tr>
</tbody>
</table>
Navigate through the possible combinations through:

- A series of technology compatibilities (i.e. some technologies options for one subsystem may not be compatible with technologies in another subsystem)
- Technology filters (i.e. all must be at least a TRL = 8)
- Technologies that will benefit important requirements
Surrogate models

Equation based regressions of complex codes
Negligible loss in accuracy of original tools
Can be executed in fractions of a second instead of hours or days
On-the-fly tradeoffs yield results that otherwise may not have been discovered

Bringing Modeling & Simulation **Forward** in the Decision Making Process
**DoD Strategic Guidance**

**Joint Operating Concepts**
- Joint Functional Concepts

**Gap Analysis**
- Material Solution Analysis
- ICD
- MDD
- Analysis of Alternatives

**Concept Refinement**
- Milestone A

**Tech Development**
- Milestone B

**Eng. Manufact. & Develop.**
- Milestone C

**Production**
- FRP

**Deployment**
- IOC

---

**GTRI IEWS Program Support**
- **✓ IEWS** Counter RC-IED Technology Discovery
- Pre-AoA planning
- Provide Subject Matter Expertise as necessary
Contents

• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)
    Bishop, et al.
  – Tennenbaum Institute (TI)
    Bodner, Rouse, et al.
  – GTRI SE Initiative
    Ender, et al.
  – Aerospace Systems Design Lab (ASDL)
    Mavris, et al. [see related topics in Ender et al.]
  – Model-Based SE Center (MBSEC)
    McGinnis, Paredis, Peak, et al.

• Summary
• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)
    Bishop, et al.
  – Tennenbaum Institute (TI)
    Bodner, Rouse, et al.
  – GTRI SE Initiative
    Ender, et al.
  – Aerospace Systems Design Lab (ASDL)
    Mavris, et al.
  – Model-Based SE Center (MBSEC)
    McGinnis, Paredis, Peak, et al.

See also our work in RT21 and RT24

• Summary
Model-Based Systems Engineering Using SysML

Excavator Testbed (2007-2009)

Abstract

This presentation highlights Phase 1 results from a modeling & simulation effort that integrates design and assessment using SysML. An excavator testbed illustrates interconnecting simulation models with associated diverse system models, design models, and manufacturing models. We then overview Phase 2 work-in-process including a mobile robotics testbed and associated SysML-driven operations demonstration.

The overall goal is to enable advanced model-based systems engineering (MBSE) in particular and model-based X (MBX) [1] in general. Our method employs SysML as the primary technology to achieve multi-level multi-fidelity interoperability, while at the same time leveraging conventional modeling & simulation tools including mechanical CAD, factory CAD, spreadsheets, math solvers, finite element analysis (FEA), discrete event solvers, and optimization tools.

This Part 1 presentation overviews the project context and several specific components. Part 2 focuses on manufacturing aspects including factory design, process planning, and throughput simulation.

This work is sponsored by several organizations including Lockheed and Deere and is part of the Modeling & Simulation Interoperability Team [2] in the INCOSE MBSE Challenge (with applications to mechatronics as an example domain).

[1] The X in MBX includes engineering (MBE), manufacturing (MBM), and potentially other scopes and contexts such as model-based enterprises (MBE).

Citations

  NDIA M&S Committee Meeting, Arlington, Virginia.
- Main team web page: http://www.pslm.gatech.edu/projects/incose-mbse-msi/
- These publications:

Contact

Russell.Peak@gatech.edu, Georgia Institute of Technology, Atlanta, www.msl.gatech.edu
Excavator Modeling & Simulation Testbed

Sample Artifacts
Manufacturing Use Cases

[McGinnis et al.]
Process Planning Model
Functional modeling style using SysML activities
[McGinnis et al.]
eM-Plant Simulation

Discrete event model auto-generated from SysML

[McGinnis et al.]
Exploration of System Architectures

Problem Statement

Given:
- Component models
- Objectives / preferences

Find:
- Best system architecture
- Best component parameters
- Best controller

How to connect and size these?
Designer’s Dilemma
M&S Risk/Benefit vs. Cost

Level of Exploration / Optimization

Level of Fidelity

Level of Effort Required
Both Problem Formulation and Problem Solution phases are implemented in ModelCenter
SysML Parametrics

*Peak et al.*

- Road scanning system using unmanned aerial vehicle (UAVs)
- UAV-based missile interceptor system trade study
- Space systems (tutorials): orbit planning; mass/cost roll-ups
- Space systems (studies/pilots): FireSat (INCOSE SSWG), ...
- Space systems (actuals): science merit function, ...
- Environmentally-conscious energy systems / smart grid
- Manufacturing “green-ness” / sustainability assessments
- Regional water management systems (e.g. South Florida)
  ...
- Mechanical part design and analysis (FEA)
  ...
- Wind turbine supply chain management
  - Insurance claims processing and website capacity model
  - Financial model for small businesses
  - Banking service levels model
  ...

*Next-Generation Spreadsheet Technology++*
*(object-oriented, multi-dimensional, …)*
SysML Model: Global Supply Chain Mgt. & Optimization

supply chain metrics (per-week): capacity, cost, lateness, risk, ...

- Generic (shown)
- Wind turbine-specifics (not shown)

Sources: Dirk.Zwemer@InterCAX.com and Georgia Tech
Ex. Given 100’s of product orders and sourcing plans for the next 12 months, what percent of my business is at-risk if Supplier X does not deliver, or if Part Y becomes obsolete?
Model “DNA Signatures” Using SysML Parametrics
Panorama Tool by Andy Scott (Undergrad Research Asst.) and Russell Peak (Director, Modeling & Simulation Lab)
Examples as of ~9/2009 — Low/Medium Complexity

Test: Match the actual model titles (below) to their “DNA signatures” with imagined titles (left).

___g___ 1. South Florida water mgt. (hydrology) model
___a___ 2. 2-spring physics model
___e___ 3. 3-year company financial model
___c___ 4. UAV road scanning system model
___b___ 5. Car gas mileage model
___d___ 6. Airframe mechanical part model
___f___ 7. Design verification model
(automated test for two Item 6. designs)

www.msl.gatech.edu
Recent Models: ~Medium Complexity

supply chain metrics

mfg. sustainability: airframe wing

electronics recycling network

“Galaxy with Black Hole”

“Turtle”

“Tumbleweed”

mfg. sustainability: automotive transmissions

“Turtle Bird”

“Angler Fish”
SysML/MBSE Curriculum & Formats

Statistics as of Sept 2010 — www.pslm.gatech.edu/courses

- Full-semester Georgia Tech academic courses
  - ISYE / ME 8813 & 4803: Since Fall 2007 (~95 students total)

- Industry short courses
  - Collaborative development & delivery with InterCAX LLC
  - Multiple [offerings, ~students] and formats since Aug 2008
    » SysML 101 [14, ~260]; SysML 102 (hands-on) [12, ~205]
  - Modes:
    » Onsite at industry/government locations
    » Open enrollment via Georgia Tech (Atlanta, DC, Orlando, Vegas, ...)
    » Web-based “live” since Apr 2010
  - Coming soon: 201/202, 301/302 (int/adv concepts, OCSMP prep, ...)

- Georgia Tech Professional Masters academic courses
  - Professional Masters in Applied Systems Engineering
    www.pmase.gatech.edu
  - ASE 6005 SysML-based MBSE course - Summer 2010
  - ASE 6006 SE Lab (SysML-based system design project) - Fall 2010
Contents

• Introduction

• Selected SE-related efforts
  – Professional Masters in SE (PMASE)  
    Bishop, et al.
  – Tennenbaum Institute (TI)  
    Bodner, Rouse, et al.
  – GTRI SE Initiative 
    Ender, et al.
  – Aerospace Systems Design Lab (ASDL)  
    Mavris, et al.
  – Model-Based SE Center (MBSEC) 
    McGinnis, Paredis, Peak, et al.

See also our work 
in RT16 and RT25

See also our work 
in RT21 and RT24

• Summary
Georgia Tech as part of SERC

• Pleased with collaboration in SERC to date
• Looking forward to new opportunities in SERC together